IEC TR 62933-4-200

Edition 1.0 2024-04

TECHNICAL REPORT

colour inside

Electrical Energy Storage (EES) Systems – Part 4-200: Guidance on environmental issues – Greenhouse gas (GHG) emission assessment by electrical energy storage (EES) systems

IEC TR 62933-4-200:2024-04(en)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

IEC TR 62933-4-200

Edition 1.0 2024-04

TECHNICAL REPORT

colour inside

Electrical Energy Storage (EES) Systems –
Part 4-200: Guidance on environmental issues – Greenhouse gas (GHG) emission assessment by electrical energy storage (EES) systems

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 13.020.30

ISBN 978-2-8322-8728-6

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

ELECTRICAL ENERGY STORAGE (EES) SYSTEMS –

Part 4-200: Guidance on environmental issues – Greenhouse gas (GHG) emissions assessment by electrical energy storage (EES) systems

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TR 62933-4-200 has been prepared by IEC technical committee 120: Electrical Energy Storage (EES) systems. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
120/351/DTR	120/364/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62933 series, published under the general title *Electrical energy storage (EES) systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

ELECTRICAL ENERGY STORAGE (EES) SYSTEMS –

Part 4-200: Guidance on environmental issues – Greenhouse gas (GHG) emissions assessment by electrical energy storage (EES) systems

1 Scope

This part of IEC 62933, which is a Technical Report, describes aspects on reduction of greenhouse gas (GHG) emissions associated with electrical energy storage systems (EES systems), and presents current practices, research activities and related researches in each country.

This document is intended to be used by those involved in design, development and use of EES systems, the grids and the renewable energy sources in the grids, where various applications, including but not limited to long term ones (peak shaving, load levelling, backup power, etc.) and short term ones (frequency regulation, renewable energy stabilization, etc.), are considered.

The current version of this document is structured in as follows: Clause 4 describes the general concept of GHG emissions reduction, Clause 5 describes the current practices, and Clause 6 describes academic approaches.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
battery energy storage system
BESS
electrical energy storage system with accumulation subsystem based on batteries with secondary cells

Note 1 to entry: The battery energy storage system includes a flow battery energy system (IEC 62932-1:2020, 3.1.15).

Note 2 to entry: Batteries are defined in IEC 60050-482:2004, 482-01-04, and secondary cells are defined in IEC 60050-482:2004, 482-01-03.

3.2
grid
particular installations, substations, lines or cables for the transmission and distribution of electricity

Note 1 to entry: The boundaries of the different parts of this network are defined by appropriate criteria, such as geographical situation, ownership, voltage, etc.

Note 2 to entry: The term grid is used as in 3.2 unless otherwise defined.

[SOURCE: IEC 60050-601:1985, 601-01-02, modified – in the term, “grid” has replaced “electric power network” and note 2 has been added.]

3.3
greenhouse gas reduction
GHG reduction
calculated decrease of GHG emissions between a baseline scenario and the project

4 General

The promotion of renewable energy (RE) is a global agenda, and in particular the mass introduction of solar and wind power is in progress. IEC White Paper “Electrical Energy Storage [1][1]” states that “Electrical Energy Storage, EES, is one of the key technologies in the areas covered by the IEC. EES techniques have shown unique capabilities in coping with some critical characteristics of electricity, for example hourly variations in demand and price. In the near future EES will become indispensable in emerging IEC-relevant markets in the use of more renewable energy, to achieve CO_2 reduction and for Smart Grids”. Thus, this document tries to address GHG (e.g. CO_2 and others) emissions reduction associated with EES systems. For example, EES systems contribute to the replacement of a number of thermal power generators in the context of long and short duration application and grid frequency control where rapid response and controllability as the major characteristics of EES systems are utilised (see Figure 1).

- As renewable energy increases, some fossil fuel power plants should be shut down, resulting in a decrease in the balancing power force.
- Frequency fluctuation becomes bigger issue because of insufficient balancing power force.
- Fast response EES systems could be a solution.

1 Numbers in square brackets refer to the Bibliography.

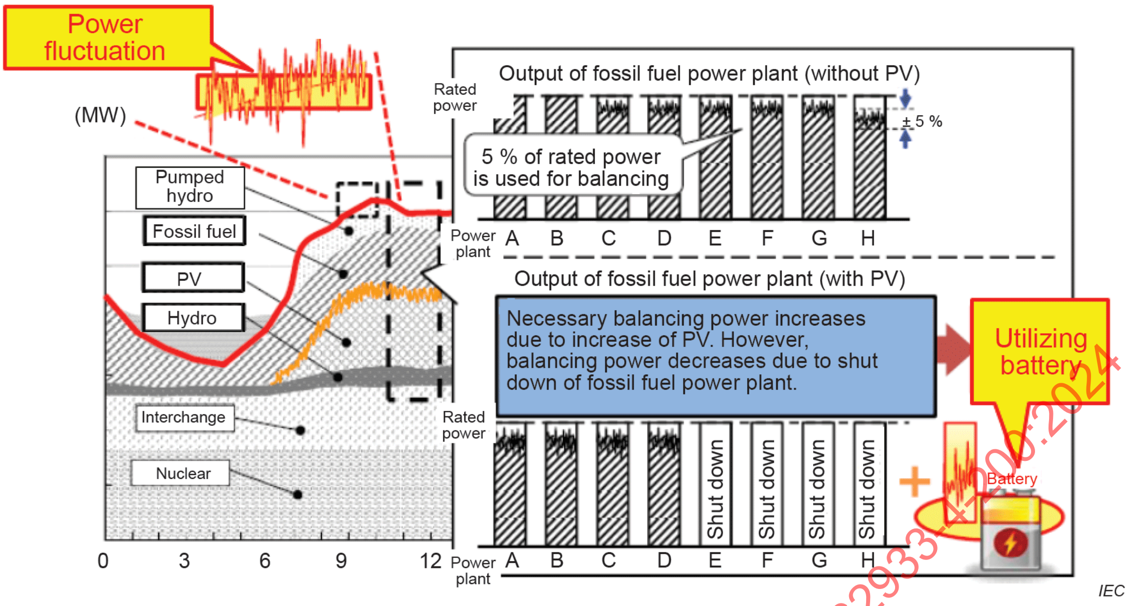


Figure 1 – Actions to take against frequency fluctuation (short duration)

As more RE has been promoted, electrical energy storage (EES) systems have become indispensable. [2] The recent key usages of EES systems, for example battery-based energy storage systems (BESS), aimed at the GHG reduction are listed below:

NOTE The terms used in the list below and in Clause 5 and Clause 6 are sometimes different from the definitions in IEC 62933-1, but the terms used in the cited references are used "as is" to avoid mistranscriptions in their inclusion in this document.

- Mobile battery loaded in electric vehicles (EVs) [3]
  The widespread use of battery-powered EVs potentially contributes to the reduction of GHG emissions in the transportation sector. In addition, EVs' contribution to GHG reductions depends on the power supply configuration when charging the EVs.
- Store surplus energy of photovoltaic (PV) power [4] [5]
  If abundant PV will be installed in a grid, its surplus energy is suppressed to maintain stability of the grid and to make effective use of excess energy. Without BESS, such curtailment means waste of energy. The BESS provides storage function of energy and addresses duck curve issue (shifting the daytime energy to night time).
- Regulation/reserve for frequency control [6] [7] [13]
  In the grid, regulation/reserve is used to balance supply/demand and maintain frequency. This regulation/reserve is supplied by a fossil fuel power plant and a pumped storage hydro power plant. BESS also has a potential to provide the regulation/reserve. EES systems can potentially replace the balancing and system services of a fossil fuel power plant and thereby enable reduction of GHG emissions in combination with RE sources.
- Load levelling (LL) and load shift [8] [9]
  One of the potential usages of BESS is load levelling (LL) and load shift. Peak demand has traditionally been served by fossil fuel power plant, while BESS has a potential to assist the peak demand. BESS contributes to reduction of the fossil fuel power plant (and thus contributes to GHG emissions reduction).
- Smart grid with BESS in physically isolated grids, for example in islands [4] [10] [11]
  100 % RE power supply is possible on isolated islands by using BESS.
- Miscellaneous assist by BESS to promote RE [12] [13]
  GHG can be reduced by BESS, since BESS enhances the introduction of RE. Distributed BESS improves the congestion of grids and compensates the imbalance caused by RE. Dynamic stability can be improved by a virtual synchronous generator which is realized by a BESS with a special power conversion system (PCS). Emergency power supply by diesel generators can be replaced by the BESS.

The tasks that are desired to be solved are:

– cost down of the BESS;
– development of more effective operation of the BESS which realizes the multiple purpose use;
– GHG emissions throughout the lifecycle of BESS.

In the following clauses, this document describes the current practices in Clause 5 and the academic approaches in Clause 6.

As for the current practices of Clause 5, it was not possible to confirm the practices aimed at contributing directly to GHG emissions reduction at the time of drafting this document. Therefore, the practices are picked up that are supposed to contribute to GHG emissions reductions.

As for Clause 6, this field is at the academic stage because it is necessary to estimate GHG emissions reduction by combining the following various conditions:

- current power supply configuration;
- power supply configuration assuming replacement by EES systems;
- usage of EVs and EES systems;
- type of energy storage technology.

In Clause 6, representative examples of papers or articles that are expected to contribute to GHG emissions reductions are given.

Furthermore, the life cycle of EES systems, as shown in IEC TS 62933-4-1, consists of four stages: acquisition, installation, operation and maintenance, and disassembly. The product state is out of the scope of the IEC TS 62933-4 series since it is before acquisition or after disassembly. The current version of IEC TS 62933-4-1 describes the "operation and maintenance" stage of the EES systems. For the "acquisition", "installation" and "disassembly" stages, the current version of IEC TS 62933-4-1only describes the potential for GHG emissions as indicated below.

- Acquisition:
  GHG emissions occur when purchasing the products "battery", "PCS", and "auxiliary equipment" that make up the EES systems and transporting them to the location where the EES systems are installed. Acquisition requires communication and GHG emissions associated with those social activities. There is also GHG emissions from the transport sector in the transportation of the products that make up the EES systems.
- Installation:
  There are GHG emissions associated with the use of assembly equipment on site. There are GHG emissions associated with the use of test power sources on-site.
- Disassembly:
  There are GHG emissions associated with the use of disassembly equipment on site.

Furthermore, the environmental aspect is required to be described in IEC documents, as stated in IEC Guide 109 and ISO Guide 64.

For more information about GHG emissions/sinks inventory, there are various documents available. For example, there is one compiled by the United States Environmental Protection Agency. [14]

The information in Clause 5 and Clause 6 is obtained using the example presented in Annex A, which is considered useful for the further development of this document in a future edition.

5 Current practices of EES systems usage in relation to GHG emissions reduction

5.1 General

Clause 5 describes the cases in each country, focusing on cases aimed at contributing to GHG emissions reduction. However, no case has been identified that directly contributes to GHG emissions reduction at the time of drafting this document.

NOTE The terms used in Clause 5 are sometimes different from the definitions in IEC 62933-1, but the terms used in the cited references are used "as is" to avoid mistranscriptions in their inclusion in this document.

5.2 Korea case (KR)

5.2.1 Case name

Korea case.

5.2.2 Overview

An electrical power company in Korea started the development of EES systems technologies for the frequency regulation (FR) service in 2014 (see Figure 2 and Figure 3).

At the demonstration stage, an EES system was installed at Jocheon substation on Jeju Island that consists of four PCSs with a rated power of 1 MW and four Li-ion batteries with 2 MWh capacity. A control system of the Jocheon EES system was repeatedly simulated and improved, and then its applicability as the fundamental control system for a FR EES system was verified. The subsequent FR EES system started to be developed in units of 4 MW PCSs and with the fundamental control system.

At the expansion stage, two large-scale FR EES systems were installed at Seo-Anseong and Shin-Yongin substations, the rated power of which are 28 MW and 24 MW, respectively. The former is for the primary frequency control (G/F, governor free) and the latter is for the secondary frequency control (AGC, automatic generation control).

After that, 11 additional FR EES systems were installed up to 2017, and as of 2019, a total of 13 FR EES systems have been in commercial operation in different places (i.e., substations). Their total rated power is 376 MW based on the rated power of the PCS and the largest rated power of the PCS is 48 MW.

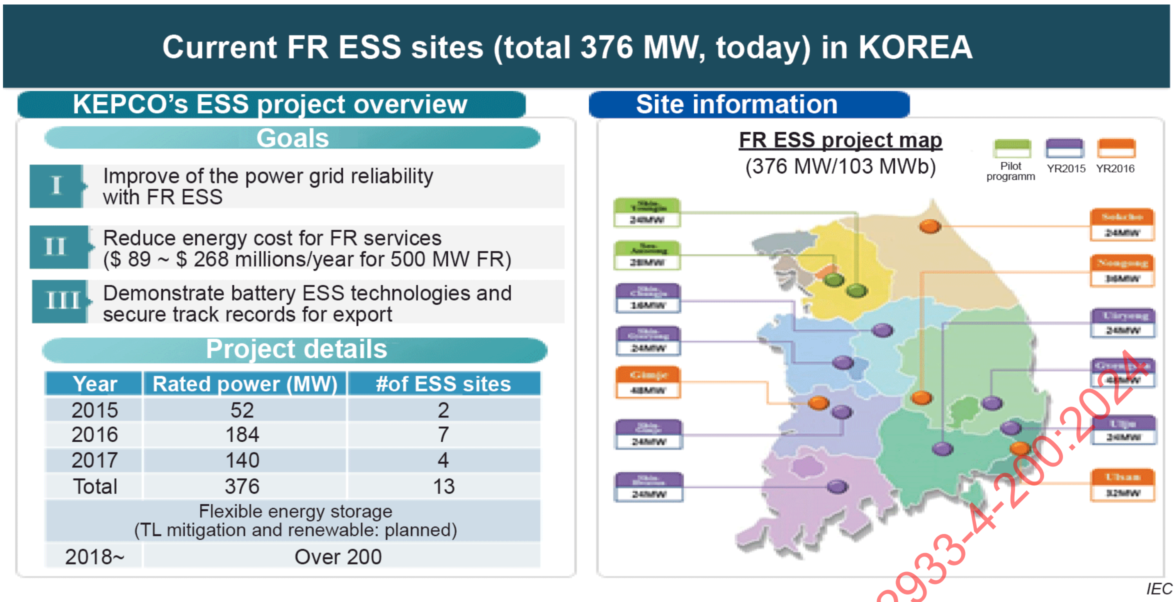


Figure 2 – Current FR EES sites in Korea

FR EESS commercial operation

Final synchronization	Substation	PCS (MW)	BAT (MW/MWh)
15,7	Seo-An-Seong	28	28/7
	Shin-Yong-In	24	24/6
	Subtotal	52	52/13
16,7	Shin-Gye-Ryong	24	24/6
	Shin-Gim-Jae	24	24/6
	Shin-Hwa-Soon	24	24/6
	Ui-Ju	24	24/6
	Ui-Ryeong	24	24/6
	Gyoung-San	48	48/12
	Shin-Chung-Ju	16	16/4
	Subtotal	184	184/46
17,7	Gim-Jae	48	48/12
	Sok-Cho	24	24/6
	Non-Gong	36	36/9
	Ul-San	32	32/8
	Subtotal	140	140/35
Total		376	376/94

IEC

Figure 3 – FR EES system commercial operation

5.2.3 View points

The fundamental control system of FR EES systems has a basic unit of 4 MW and controls four 1 MW PCSs, and it is called frequency regulation controller (FRC).

At first, the FRC measures the system frequency. Based on this, it calculates the required output of each PCS and sends a control signal to each PCS, and then the PCS discharges or charges the output from the battery according to the received control signal.

Generally, FR EES systems consist of many PCSs controlled by several FRCs. In order to control them appropriately, a control system at the upper layer called FRC master (FRCM) was developed. The FRCM monitors the status of individual FRCs and cooperates with the control function, if required. Under any situation where some FRCs are faulted, in order to satisfy the original requirement, the FRCM can make the available (or remaining) FRCs be operated for more output.

The FR EES systems in the Korea case output the assigned power within 200 ms, from the time when the system frequency is measured.

5.2.4 Economics

In the past, the FR service in KOREA was mainly provided by coal-fired power generators that have relatively inexpensive cost and proper response ability.

They were outputting less power (0,95 p.u.) than their own rated power, and the remaining power (0,05 p.u.) was in stand-by at ordinary times and was only used at times when he FR service was required.

The amount corresponding to the remaining power (0,05 p.u.) was solved by other generators which have more expensive cost; as a result, the total operation cost of whole grids used to increase.

EES systems can replace the conventional means for FR service, coal-fired power generators. In other words, an FR EES system makes the coal-fired generators able to output their rated power and also makes generators with expensive cost be less operated.

It is expected that this representative merit of FR EES systems results in the decrease of the total operation cost for the whole system.

5.2.5 FR EES systems GHG emissions reduction calculation formula

For the purpose of frequency regulation, pre-designated existing generators such as coal, oil, gas and so on, usually operate in a stand-by way during an entire year and then consume fuels as much as allocation outputs according to the types of generator units. If EES systems are replaced with them, reduction in CO_2 emissions can be expected because they are operated only if necessary. Therefore the estimation of GHG reduction during a year can be quantified as follows.

$$GHG(y) = \sum_{t=1}^{T}\sum_{i=1}^{n} P_{\text{ALLO}i}(t) * x_i - \sum_{i=1}^{T} P_{\text{ESS}}(t) * \eta_{\text{in,out}} * \gamma_{\text{ESS}}$$

Subj. to

$$\sum_{i=1}^{n} P_{\text{ALLO}i} - P_{\text{ESS}} = 0$$

where

$GHG(y)$ GHG reduction amount a year,

$P_{\text{ALLO}i}(t)$ allocation output (kW) according to generator types,

$P_{\text{ESS}}(t)$ charging and discharging output of EES system,

x_i CO_2 emission coefficient of existing generators,

γ_{ESS} CO_2 emission coefficient of EES system,

I generator types,

t time interval,

T target year,

$\eta_{in,out}$ charging and discharging efficiency (loss) of EES system.

In the above formula, the difference between the output of the fossil fuel generator for FR replaced by the EES system and the carbon emission coefficient multiplied by the loss (reduction) generated by the charging and discharging power of the EES system and the charging efficiency of the EES system are proposed as the GHG reduction. Note that γ_{ESS} can be a variable depending on the operation mode.

5.2.6 GHG emissions reduction

5.2.6.1 General

Based on the analysis of power generation source and load data, the amount of green house gas reduction was calculated by each scenario Case 1 (see Figure 5) and Case 2 (see Figure 6), in order to estimate the amount of GHG emissions reduction of the FR EES system. Since the amount of GHG reduction was calculated on the assumption of Case 1 and Case 2, the amount of GHG reduction can be estimated with actual data in the future.

5.2.6.2 Power generation sources

On the basis of the 2019 organization (draft) of electric power sources as part of the fifth basic plan for electric power supply in Korea, the following power generation sources were organized for this case study, see Table 1 (excluding hydraulic and pumped storage generation and other new and renewable generation sources).

Table 1 – Example of the power generation sources for each fuel source

Type	Total capacity (MW)	Percentage (%)	Carbon emissions (kg)/1 MWh
LNG	32 251	31,6	46,62
Soft coal	32 644	32,0	153,07
Anthracite coal	725	0,7	172
Heavy oil	3 258	3,2	82,69
Nuclear power	32 162	31,5	0
Others (by-product gases)	936	0,9	109,56
Total	101 996	100,0	

5.2.6.3 Basic load data (prior to EES system operation)

The reference to “data of estimated demands for each 5 min” was reported by Korea Power Exchange.

The following graph shows the load data for every 5 min for the first week of April, 2020 (for the whole week), see Figure 4.

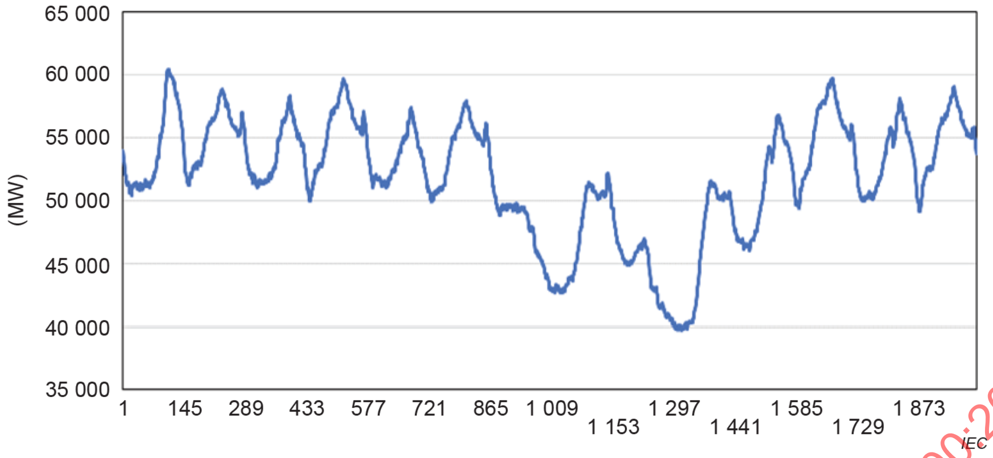


Figure 4 – Data of loads for every 5 min during the first week of April (one week)

- Frequency scenario (assumed)

On the assumption of the regular distribution that the average was 60,0 Hz and the standard deviation was 0,02 based on actual domestic frequency data, the following two frequency scenarios (Case 1, Case 2) were created and applied (see Figure 5 and Figure 6):

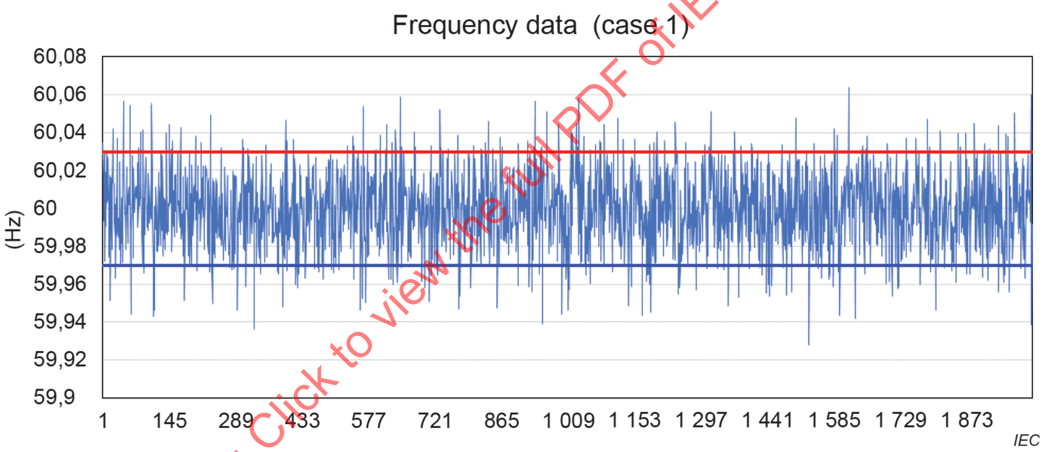


Figure 5 – Frequency scenario at intervals of 5 min (Case 1)

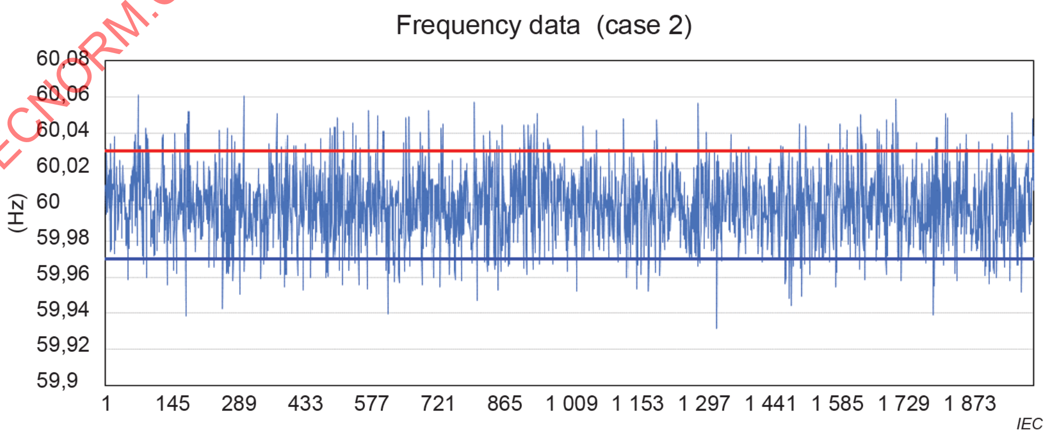


Figure 6 – Frequency scenario at intervals of 5 min (Case 2)

- FR EES system charging/discharging scenario

EES system configuration: 376 MW / 94 MWh (4C).

FR EES system operation algorithm in the normal status (see Figure 7).

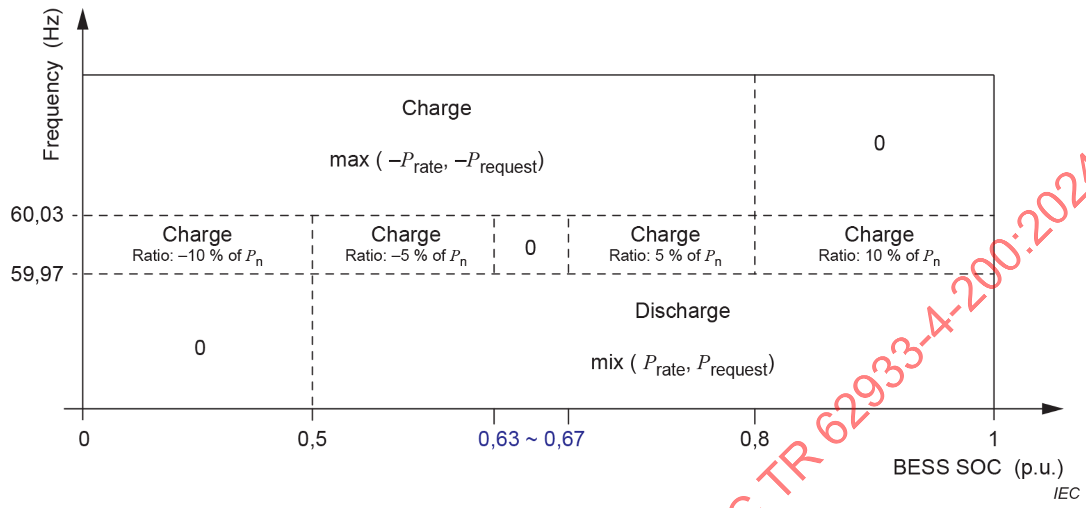


Figure 7 – FR EES system operation algorithm in the normal status

In consideration of the operation algorithms above, the EES system charging/discharging scenarios for each frequency scenario of Case 1 and Case 2 were created as shown in Figure 8 and Figure 9:

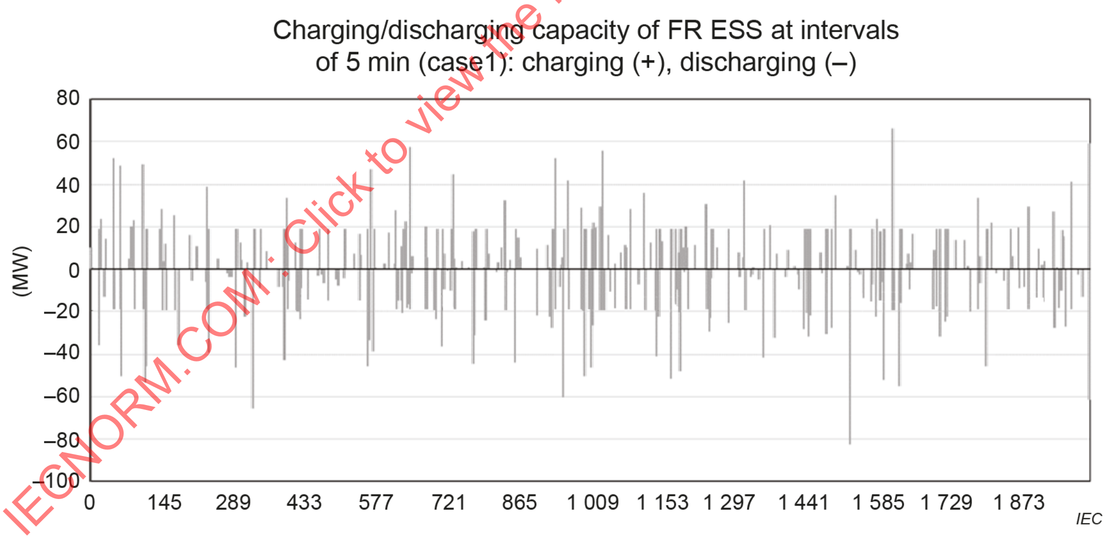


Figure 8 – EES system charging/discharging scenario at intervals of 5 min (Case1)

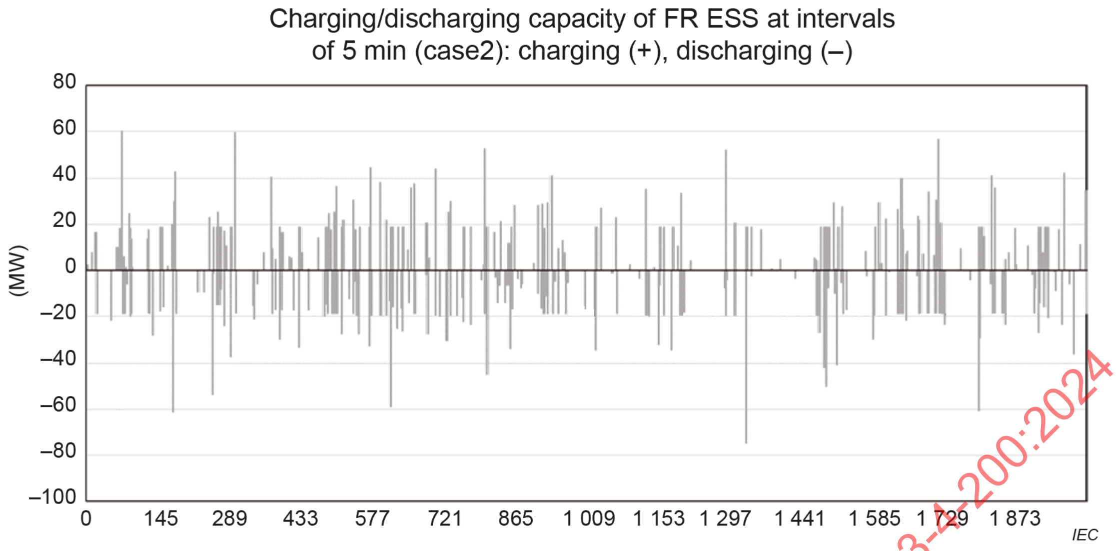


Figure 9 – EES system charging/discharging scenario at intervals of 5 min (Case2)

The EES system charging/discharging scenarios determine the final load for the two cases on the basis of the basic load.

5.2.6.4 GHG emissions reduction for FR EES system

EES systems can maintain power quality such as voltage and frequency, by supplying or absorbing power from or into EES systems when necessary. In addition, the penetration of renewable energy requires more frequency control capability in the power system. EES systems can be used to enhance the capability through the control of charging and discharging from network operators, so that the imbalance between power consumption and generation is lessened.

For the purpose of frequency regulation, pre-designated existing generators such as coal, oil, gas and so on, usually operate in a stand-by way during an entire year and then consume fuels as much as the allocation outputs according to the types of generator units which are 888 tonnes CO_{2e}/GWh for coal, 29 tonnes CO_{2e}/GWh for nuclear, and so on according to the WNA Report 2011 [15]. If EES systems are replaced with them, reduction of CO_2 emission can be expected because they are operated only if necessary. Therefore the estimation of GHG reduction during a year can be quantified in the formula given in 5.2.5.

If the existing plants of coal generation used for frequency regulation are replaced by EES systems, the CO_2 emissions can be reduced by avoiding stand-by operation of coal generator. The amount of GHG reduction during a year can be calculated by:

$$GHG(y) = \sum_{t=1}^{T}\sum_{i=1}^{n} P_{\mathrm{ALLO}i}(t) * x_i - \sum_{i=1}^{T} P_{\mathrm{ESS}}(t) * \eta_{\mathrm{in,out}} * \gamma_{\mathrm{ESS}}$$

Here, the total amount of the EES system is assumed as 1 000 MW(4 000 MWH) and the efficiency of the EES system is also 85 % for frequency regulation application. The allocation unit of nuclear, which does not emit CO_2, is used as the one for the EES system.

P_{ALLO_i} / year = 365 d × 1 000 MW × 24 h × 888 kt/MWh × 10^{-6} = 7 779 kt

$P_{\mathrm{ESS}}(t)\eta_{\mathrm{in,out}}$ / year = 365 d × 4 000 MW × 29 kt/MWh × 10^{-6} × 85 %= 36,3 kt

$GHG(y)$ = 7 742,9 kt

5.3 Cases in Japan (JP)

5.3.1 Case name

Japan case.

5.3.2 Overview of the case

In Japan, large capacity BESS such as sodium sulfur (NaS) battery systems, redox flow battery systems, and lithium-ion battery (LiB) systems have been utilized at consumer sites as load levelling and emergency power supply/voltage dip measures. By doing this, they discharge at the peak in the daytime with electricity charged with a relatively environmentally friendly power source at night, and they use charged electricity as an emergency power source without using the on-site fossil fuel system generator at the time of power failure or dips.

Recently, as measures against the negative impact of massive penetration of renewable energy (RE), attention has been paid to utilizing BESS for system frequency fluctuation, store surplus power of RE, measures against voltage of distribution lines, etc. Demonstration projects at substations and customer sites have been advanced. In this way, the adjustment power of the thermal power plant on the grid side for frequency fluctuation can be replaced with the BESS. In addition, the surplus power of the RE can be stored by the BESS without suppressing the RE output. These measures have been verified, and institutionalization for practical use is in progress.

There is a possibility that the power source derived from fossils will be reduced and these will lead to GHG reduction.

5.3.3 Utilization of conventional BESS

Japan's peak demand is sharp throughout the four seasons, including hot and humid in the summer and severe cold in the winter. In addition, Japan relies on imports from overseas for most energy resources. For this reason, load levelling has been required for a long time. For this purpose, researches for energy conservation and new energy have been promoted. Since 1980, large-capacity BESS have been developed nationwide. As a result, the development and commercialization of BESS has advanced. These BESS have been applied for single or multiple purposes such as load levelling, emergency power supply, and voltage dip countermeasures. With these applications, electricity charged by a relatively environmentally friendly power source is discharged as necessary. For example, it is used as an emergency power source without using fossil fuel-based private power generation facilities in the event of a power outage or voltage dip (see Figure 10).

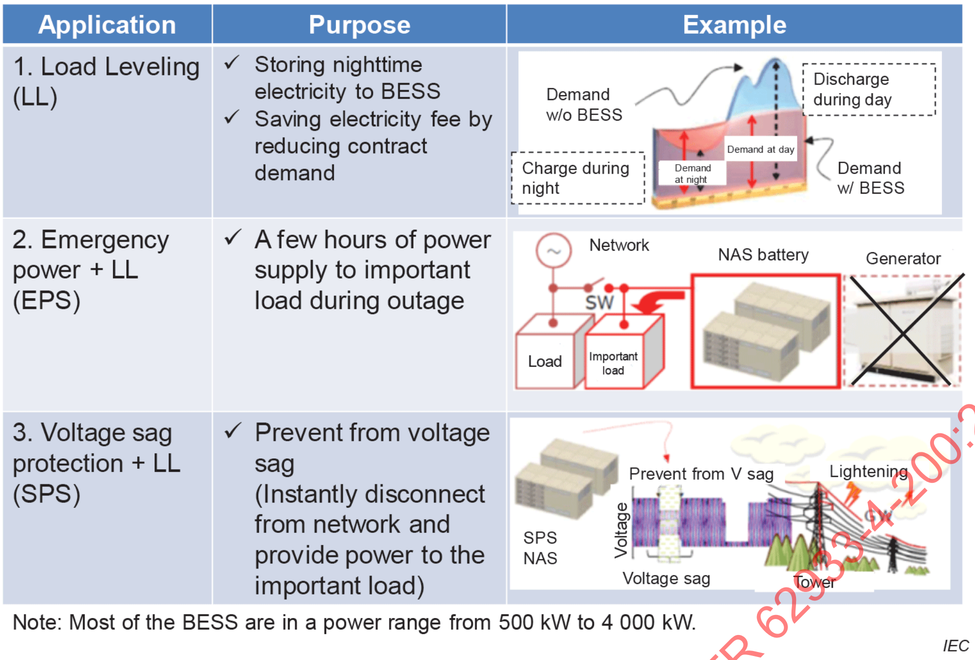


Figure 10 – Application of behind the meter

5.3.4 Advanced use of BESS

Large-scale penetration of renewable energy such as solar power generation and wind power generation has caused problems such as frequency fluctuations, surplus power, and distribution line voltage fluctuations (see Figure 11).

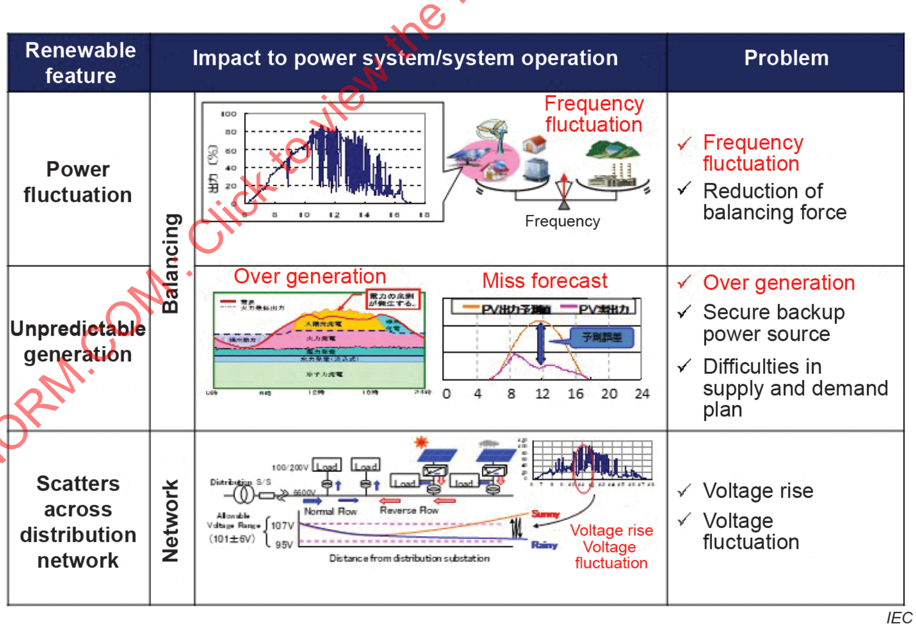


Figure 11 – Problems caused by large-scale penetration of renewable energy

The spread of renewable energy increases frequency fluctuations. As a countermeasure, both the grid side and the customer side are considering the use of storage batteries to stabilize the power system, such as frequency fluctuation mitigation (see Figure 12).

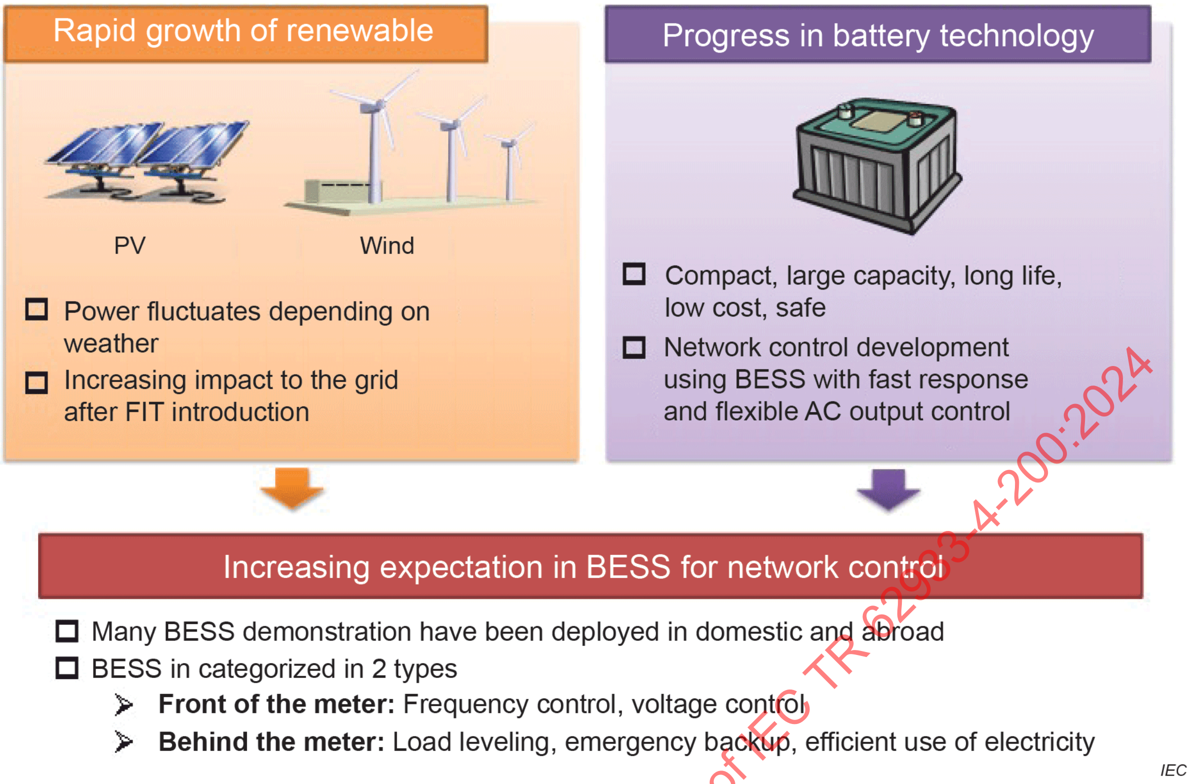
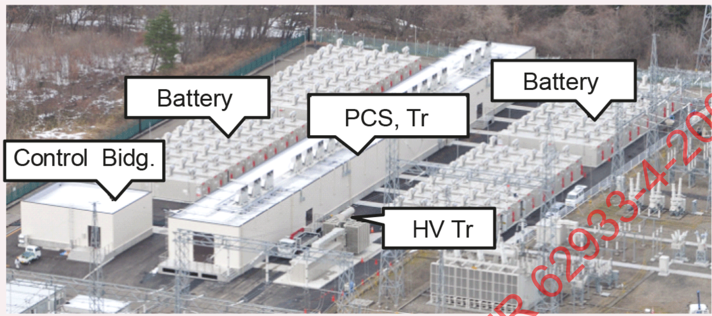


Figure 12 – Background of BESS utilization in the power system

5.3.5 Application example on the grid side

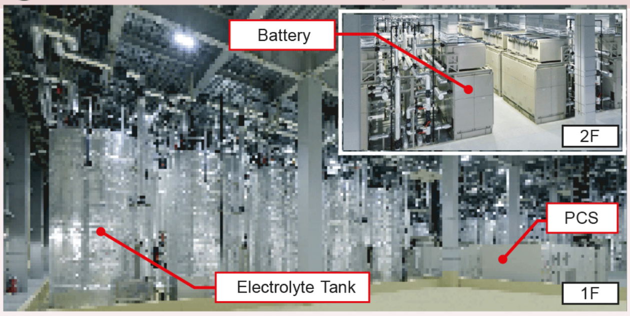
In Japan, many projects are being carried out on the utilization of BESS on the grid side, and representative examples are introduced as follows (see Figure 13, Figure 14 and Figure 15).

Outline of demonstration	
Location	Nishisendai S/S of Tohoku Electric Power
Type	LiB
Power/energy	20 000 kW (Short period 40 000 kW) • 20 000 kWh
Demo period	2015 ~ 2019
Purpose	① Reducing short duration frequency changes caused by renewable ② Development of control technology of BESS
Outlook	

IEC

(SOURCE: IEEJ Technical Report No 1403:2017 [19][2])

Figure 13 – BESS for reducing grid frequency changes at Nishisendai substation (S/S)

Demonstration Outline	
Location	Minamihayakita S/S of Hokkaido Electric Power
Type	Redox Flow
Power/energy	15 000 kW/60 000 kWh
Demo period	2015 ~ 2019
Purpose	① Optimization of BESS operation to mitigate renewable impact to network ② Evaluation of Redox Flow performance
Outlook (Indoor)	

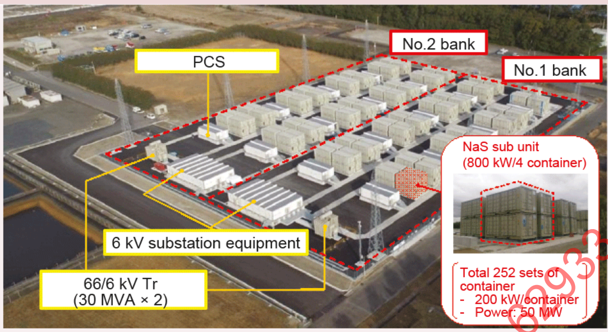
IEC

(SOURCE: Hokkaido Electric Power Co, Inc.[3])

Figure 14 – Large BESS demonstration at Minamihayakita substation (S/S)

[2] Reproduced from IEEJ Technical Report No 1403:2017, with the permission of Tohoku Electric Power NW.

[3] Reproduced with the permission of Hokkaido Electric Power Co, Inc.

Demonstration Outline	
Location	Buzen battery S/S of Kyushu Electric Power
Type	Sodium Sulfur (NaS)
Power/energy	50 000 kW/300 000 kWh (25 000 kVar)
Demo period	2016 ~ 2017
Purpose	① Energy shift of over generated renewable ② Evaluation of efficient use of BESS
Outlook	

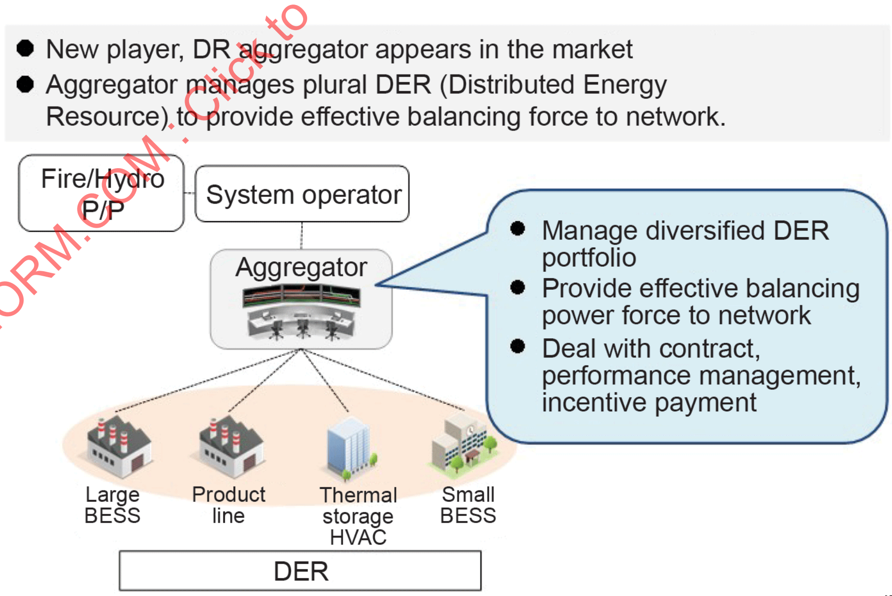
IEC

(SOURCE: IEEJ Technical Report No 1403:2017 [19][4])

Figure 15 – Energy shift demonstration by large BESS at Buzen battery substation (S/S)

5.3.6 Application example on the demand side

Supply and demand adjustment such as frequency fluctuation is usually done by the system side, but supply and demand adjustment can be similarly made by increasing or decreasing the load on the demand side (negative watt / positive watt). As a demonstration test, an aggregator that bundles BESS, generators, loads, and the other system components on the demand side adjusts supply and demand according to system commands (see Figure 16).



IEC

Figure 16 – Role of aggregator for demand response (DR)

4 Reproduced from IEEJ Technical Report No 1403:2017, with the permission of Kyushu Electric Power NW.

In supply-demand adjustment, the certainty of negative watt and positive watt is required. The requirements are confirmed in a demonstration test on the customer side utilizing the high speed and high precision controllability of the BESS (see Figure 17).

- Jan. 16 2018 DR request at 13:45 (15min. In advance), DR during 14:00 to 15:00
- DER: 6 sites (NAS: 5 sites, LiB + generator: 1 site)
- Total DR: 6 350 kW (14:00 to 14:30), 6 161 kW (14:30 to 15:00)

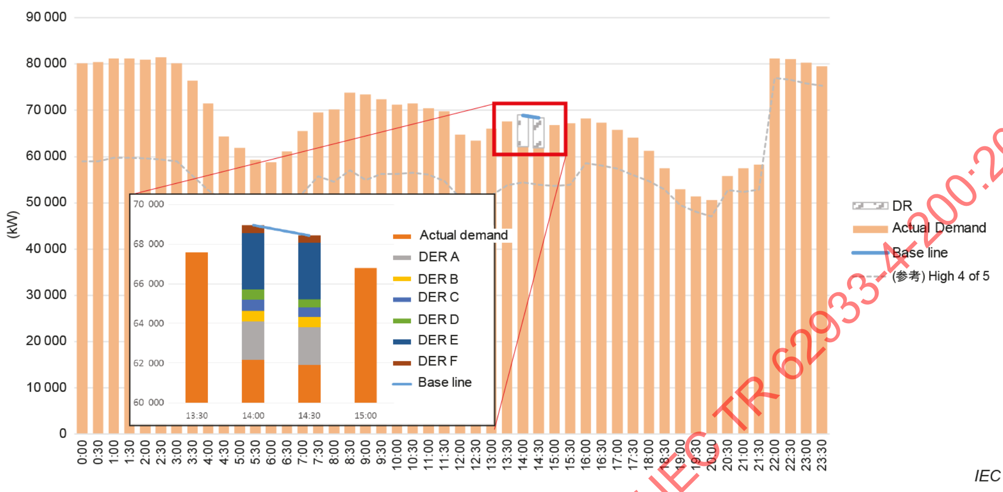


Figure 17 – Virtual power plant (VPP) demonstration example

By utilizing the BESS for supply and demand adjustment, it becomes possible to reduce or stop the thermal power generator which had to perform partial load operation or standby operation as a conventional adjustment force. This will reduce fossil power sources and reduce GHG emissions.

Also, when there is a surplus of renewable energy, the power generation output will be suppressed. By storing and using this surplus power in a BESS, environmental friendliness is improved.

5.3.7 Examples of consideration of GHG reduction by EES systems

A first order assessment of the environmental effects indicates that the introduction of BESSs increases GHG emissions by the amount of charge-discharge losses if the energy source is carbon based, and not solar or wind. But because batteries can change the time energy is taken from and released back to the grid and also the time it is used locally there, significant economic and GHG benefits can be realised especially through the coordination of supply and demand. An example of this is found in the Kyushu region of Japan where there are many PV installations. In Kyushu PV power generation output has been curtailed according to supply and demand conditions. Modelling and simulations were carried out with the assumption that industrial and commercial users will install BESSs for the purpose of reducing the maximum power and contract demand to reduce electricity costs, and also that PV owners will install BESSs in order to increase revenue from sales when the feed in premium (FIP) system is introduced.

For the case where the total power supply cost is minimized in the energy chain, CO_2 emissions were calculated both before and after the BESS was installed, and the amount of reduction was calculated from the difference (see [18] for details).

CO_2 emissions were reduced from 26,7 million tons/year to 25,8 million tons/year by the introduction of BESSs, and the reduction rate in this region was 3,3 %.

The following is an overview of the simulation method.

<Objective function>: Minimizing the total cost related to thermal power and EES system

$$OBJ = \sum_{i \in p,s} fixc(i) \cdot CAP(i) + \sum_{f} \sum_{t=1}^{8760} \left\{ u_f + c \cdot x_f \right\} \cdot F(f,\ t)$$

when $F(f,\ t) = \sum_{p,mode,t} \dfrac{X(p,mode,t)}{\eta_{p,mode}} + \sum_{p,smode,t} sf_{p,smode} \cdot MW(p,smode,t)$

$$CAP(p) = \sum_{mode} OPMW(p,\text{mode},t) + \sum_{smode} NOPMW(p,smode,t)$$

<Constraint>

(1) Matching between hourly energy supply and demand at sending ends

$$demand(t) + \sum_{s,t} CHARGE(s,t) = \sum_{p,mode,t} X(p,mode,t) + \sum_{r,t} \left\{ output(r,t) - CURTAIL(r,t) \right\} + \sum_{q,t} output(q,t) + \sum_{s,t} DISCHARGE(s,t)$$

(2) Hot reserve for unforeseen change of demand

$$\sum_{p,mode} \left(1 - aux_p\right) \cdot OPMW(p,mode,t) + \sum_{s} CAP(s) + \sum_{q} output(q,t) + \sum_{r} sup_r \cdot output(r,t) \geq (1 + resrate) * demand(t)$$

(3) Adequate ability of frequency control by thermal power, pumped hydro and EES sytem for the total amount of short period fluctuation included in variable renewable power output and demand

(4) Required hours to start operations of thermal power (constraints of transfer timing from *smodes* to *modes*)

(5) Output change speed of thermal power (constraints among *modes*)

(6) Thermal power output $X(p,mode,t)$ is constrained by $OPMW(p,mode,t)$. For example, when *mode* is 90 %,

$$X(p,90\ \%,t) = 0{,}9\left(1 - aux_p\right) \cdot OPMW(p,90\ \%,t)$$

(7) *CHARGE* and *DISCHARGE* are constrained by the MW capacity of the battery, and they change the state of charge (SOC) of the battery. The *SOC* is constrained by MWh capacity of battery and affected by a charge-discharge cycle loss and auxiliary loss like air conditioners.

(8) Maximum value of annual total of *CURTAIL* considering economical assessment of PV and wind power and others

<Assessment of CO_2 emissions>

$$GHG = \sum_{f} \sum_{t=1}^{8760} x_f \cdot F(f,t)$$

if $GHG = GHG_0$ when $CAP(ESS) = 0$ (without EES system)

Annual GHG reduction:

$$\Delta GHG = GHG_0 - \sum_{f} \sum_{t=1}^{8760} x_f \cdot F(f,t)$$

- When $CURTAIL = 0$ in Constraint (1), the increase of $DISCHARGE$ and $CHARGE = 0$ decreases thermal power output X, so GHG is decreased.
- When $CURTAIL > 0$, the increase of $CHARGE$ and $DISCHARGE = 0$ decreases $CURTAIL$, and enables more $DISCHARGE$ later.
- The capacity of PV and wind power is economically constrained by the forecasted curtailment rate. The decrease of curtailment increases PV and wind energy instead of thermal power, and decreases GHG.
- Hot reserve by $CAP(ESS)$ in Constraint (2) decreases the required operating thermal power capacity $OPMW$ and thermal power output X in Constraint (6), then GHG is decreased.

<Nomenclature>

Endogenous variables are shown in capitals, and exogenous variables in small letters

p:	thermal generation type including coal, LNG and oil
q:	other generation type, including nuclear, hydro, geothermal, and biomass power
r:	variable renewable generation type including photovoltaic and wind power
s:	storage facility type including pumped hydro and EES system
t:	hourly time for a year
$fixc(p)$:	annual fixed costs for facility p [yen/MW/year]
$CAP(p)$:	total capacity of facility p [MW]
u_f:	unit cost for fuel f [yen/MJ]
x_f:	CO_2 emission coefficient for fuel f [ton-CO_2/MJ]
c:	market price of CO_2 [yen/ton-CO_2]
$F(f,t)$:	consumption of fuel f at a period from t-1 to t [MJ]
$mode$:	operation mode {100 %, 90 %, 75 %, 60 %, 50 % (liquefied natural gas combined cycle (LNGCC) only), 45 % (coal and oil), 30 % (coal and oil)} of rated maximum power output of thermal power plants
$smode$:	non-output mode {stop, cold-start, hot-start, banking (standby)} of thermal power plants
$X(p,mode,t)$:	power output by facility p in a $mode$ at a period from t-1 to t [MWh]
$\eta_{p,mode}$:	thermal efficiency of thermal power p in a *mode* considering lower efficiency at partial load [MWh/MJ]
$sf_{p,smode}$:	fuel consumption in a starting mode $smode$ [MWh/MW]
$MW(p,smode,t)$:	total capacity of thermal power p in an $smode$ at a period from t-1 to t [MW]
$demand(t)$:	electric energy demand at a period from t-1 to t [MWh]
$output(q,t)$:	electric energy output by other generation type q [MWh]

$output(r,t)$: electric energy output by renewable type r before the curtailment [MWh]

$CHARGE(s,t)$: charged energy to storage facility s from t-1 to t [MWh]

$DISCHARGE(s,t)$: discharged energy from storage facility s from t-1 to t [MWh]

$CURTAIL(r,t)$: curtailed energy of renewable generation type r from t-1 to t [MWh]

$OPMW(p,mode,t)$: operating capacity of thermal type p in a $mode$ from t-1 to t [MW]

$NOPMW(p,mode,t)$: not operating capacity of thermal type p in a $mode$ from t-1 to t [MW]

aux_p: auxiliary power ratio of thermal type p

sup_r: sure supply ability rate of PV and wind power (ex. monthly average rate of least 5)

$resrate$: operation reserve rate (for example 3 %)

5.3.8 Multiple use of BESS

In order to improve the cost performance of the BESS, multi-use of the BESS is effective. This includes improving environmental performance to reduce GHG emissions (see Figure 18).

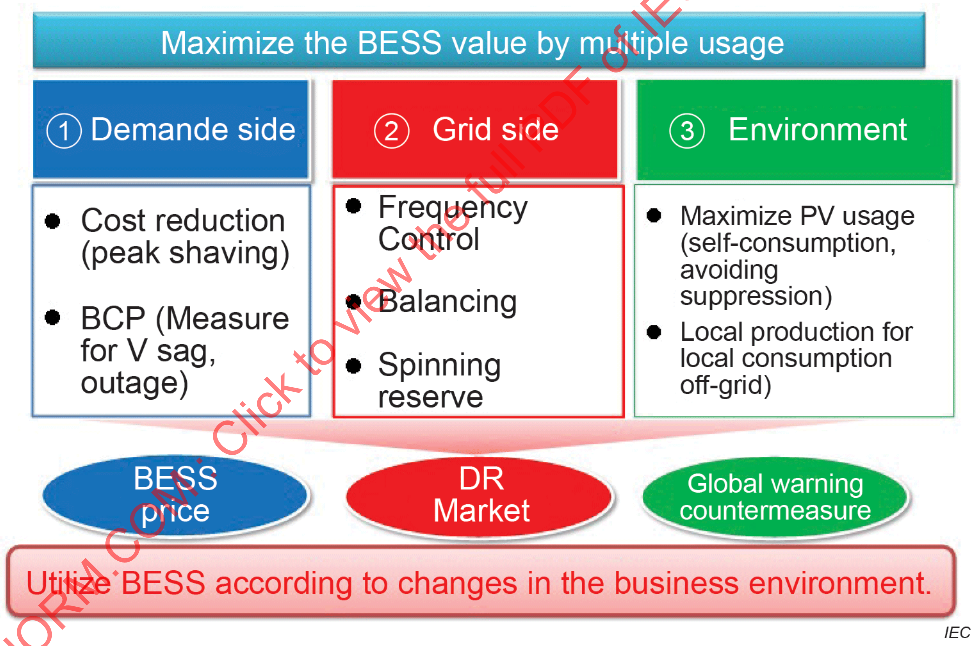


Figure 18 – High added-value of a BESS

5.4 Cases in Australia (AU)

5.4.1 Case name

Australia case.

5.4.2 Overview of the case

5.4.2.1 General

The Commonwealth of Australia has six states and two territories each operating with a high degree of autonomy. The largest state, New South Wales (NSW), with about one quarter of the country's population uses about one third of the total electrical energy. NSW has a firm emissions reduction objective and an energy security plan as outlined below.

5.4.2.2 Energy efficiency in NSW's Net Zero Plan

The Net Zero Plan Stage 1: 2020 to 2030 is the foundation for NSW's action on climate change and the objective to reach net zero emissions by 2050. It sets out the NSW Government's plan to reduce emissions over the next decade while growing the economy, creating new jobs and lowering the cost of living. Stage 1 of the Net Zero Plan is expected to deliver a 35 % reduction in emissions in NSW by 2030 compared to 2005 levels.

The plan is expected to attract $11,6 billion of private investment to NSW and support 2 400 new jobs. From 2020 to 2030 the Net Zero Plan will be supported by $1,97 billion of joint funding from the NSW and Commonwealth Governments, as agreed in the NSW Energy Package MoU.

This funding will support a suite of energy and emissions reduction initiatives, including an Energy Efficiency Program to reduce electricity bills, ease pressure on the electricity grid and reduce emissions. The Energy Efficiency Program is in the design phase, with consultation with key stakeholders underway. The program will consider extending current government programs such as the Solar for Low Income Households or LED street lighting replacement, where those initiatives have demonstrated strong results for both consumers and the environment.

5.4.2.3 Energy Security Safeguard

The NSW Energy Savings Scheme has been highly successful in delivering energy savings over the last decade. Activities implemented under the scheme between 2009 and 2018 will deliver energy savings of about 27 000 GWh and bill savings of about $5,6 billion by 2028.

The government is expanding the scheme under the Energy Security Safeguard. The Safeguard includes an energy efficiency scheme that will run until 2050 and a new certificate scheme to support technologies that reduce demand at peak times. These technologies can include batteries, smart pool pumps and electric vehicle chargers.

The government recently consulted stakeholders on the scheme's design, with submissions closing on 22 June 2020. The scheme design is currently being developed, ensuring that it complements and is consistent with existing and emerging peak demand reduction mechanisms nationally.

5.4.3 The NSW energy programs

5.4.3.1 Emerging Energy program

The $75 million Emerging Energy program provides grant funding to assist with the development of innovative, low emissions, large-scale electricity and storage projects in NSW. By reducing barriers to invest in emerging technologies, it supports affordable, reliable and clean energy across the State. The program sets an emissions intensity maximum limit of 05 t of carbon dioxide equivalent per megawatt hour of electricity generated. This limit was set to align with the requirements of the NSW Climate Change Fund, the program's funding source. There are two funding streams to support activities that accelerate the development of on-demand, electricity projects:

1) Capital projects – activities that will assist with the construction of a dispatchable electricity project.
2) Pre-investment studies – activities that will lead to the development of a dispatchable electricity project.

Grants have now been awarded across both streams. In the capital projects stream, grant funding of approximately $37,5 million is being provided to four projects totalling 170 MW leveraging almost $233 million in private investment. Three different technologies are being supported through the grants, which include; a gas-battery hybrid, a virtual power plant and two large-scale lithium batteries. The Department is working with the Australian Renewable Energy Agency to fund additional projects, with further details to be announced once contracts are finalised.

The eight successful pre-investment studies recipients are investigating projects with the potential to deliver 2 100 MW of on-demand electricity in NSW and leverage almost $2 billion in private investment. Technologies include, pumped hydro, compressed air and large scale batteries.

5.4.3.2 Solar for Low Income Households program

Solar for Low Income Households program is trialling a new way to help people on low incomes reduce their electricity bills by installing 3 kW solar systems on their homes. The program looks to improve energy affordability by helping households unlock long term savings on their electricity bills. Low-income households are the most vulnerable to increasing electricity prices and the upfront cost of purchasing a solar system remains a barrier. The program aims to:

– reduce electricity bills by more than the Low Income Household Rebate and improve electricity affordability for low-income households;
– install up to 3 000 solar power systems or 9 MW of distributed behind-the-meter renewable energy generation;
– trial a more effective way of supporting low-income households;
– reduce greenhouse gas emissions.

This program is only available to a limited number of households that live in selected regions and meet the eligibility criteria. This includes receiving the Low Income Household Rebate (LIHR) and holding a valid Pensioner Concession Card or Department of Veterans' Affairs Gold Card. Households that participate in the trial are expected to save approximately $600 p.a. – more than two times greater than the annual $285 LIHR payment. The average household will be better off by over $300 in year one by participating in the trial.

This NSW Government initiative is run by the Department of Planning, Industry and Environment which has selected three solar installation companies to deliver this program. The Net Zero Plan Stage 1: 2020 to 2030 states that the NSW Government will consider extending the trial pending its success in respect of outcomes for consumers and the environment.

5.4.3.3 Regional Community Energy program

The Regional Community Energy program funds community energy projects in regional NSW and the project objectives are to:

– improve energy reliability and the integration of renewables in regional communities;
– improve energy affordability and resilience for regional communities;
– deliver bill savings through improved access to information and services;
– build energy literacy and capacity in regional NSW communities.

The program will run under three separate schemes to achieve these objectives:

1) Grants from the Regional Community Energy Fund for projects that are innovative or generate on-demand renewable energy and benefit the local community.
2) Funding for community energy hubs that improve household and small business access to expert energy advice.
3) Funding for regional and remote communities to install emergency backup systems for key disaster management and evacuation locations to increase disaster resilience.

Earlier this year, the Regional Community Energy Fund, awarded grants to seven projects, worth approximately $15,4 million. These projects will unlock nearly 17,2 MW in electricity generation and up to 17,9 MW/39,3 MWh of energy storage, leveraging approximately $36 million in private investment. Project examples include community owned dispatchable solar and battery systems, a solar garden, a community battery and a NSW first hydrogen energy storage system alongside a solar-battery system to store renewable energy. Projects are required to be commissioned by June 2022. Each funding recipient will share their learnings, supporting other regional communities to take control of their energy future.

5.4.3.4 Empowering Homes program

The Empowering Homes program aims to install 3 000 MWh of renewable storage on the low voltage side of the electricity network in NSW, by making solar-battery systems incentives available to NSW households. The program aims to unlock up to $3,2 billion of private investment in clean energy technology over the next 10 years and reduce barriers for households to access the benefits of solar-battery solutions.

The Empower Homes program will help increase the capacity of the NSW energy system to manage increasing levels of household solar, and put downward pressure on energy costs for all users. The program will help reduce household electricity bills, improve energy system reliability and security, support the development of a robust and vibrant distributed energy resources (DER) sector, and reduce energy sector emissions.

The Empowering Homes program is a 2019 election commitment and was opened to the public in February 2020 as a pilot in the Hunter region. The pilot is available for 12 months and will test customer demand, safety and quality to ensure success for the full program. The Empower Homes program will be rolled out across NSW in early 2021.

Public safety and consumer protection have been extremely important considerations in the design of this program. Strict eligibility criteria have been established for installers and products that can be sold under the Empowering Homes pilot. The product eligibility criteria ensure that these products support network stability during disruptions and are able to interface with Virtual Power Plant platforms, enabling networks to handle higher levels of rooftop solar in future.

5.4.3.5 Smart Batteries for Key Government Buildings

The Smart Batteries for Key Government Buildings trial projects will install up to 3 000 kWh of smart battery storage capacity at NSW Government sites to test the benefits of solar and battery technologies for these kinds of facilities. The batteries will be utilised to demonstrate innovative solutions to manage peak demand or load shift energy usage for schools, health facilities, and other government sites. These trial projects will help the NSW Government to develop a deep understanding of the range of issues and benefits adding batteries and large solar PV systems to NSW Government sites can produce.

The batteries will also help to drive an increased uptake of solar photovoltaic systems with an estimated additional 1 200 kW of solar PV also being added.

By installing solar-battery systems at their facilities, NSW government agencies are expected to make significant energy and operational cost savings, as well as reducing the impact of government assets on peak demand on the network. This reduction in demand during peak times on the network, coupled with the ability to control the fleet of government batteries, providing energy and support services to the grid when needed, can support the security and reliability of the NSW electricity grid.

The learnings generated from these, and other solar-battery projects will be used to inform future clean energy projects and initiatives.